Boundary Layer Marine Stratus: Diurnal Variability in Microphysics

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LONG-TERM GOALS

The goal of this research is to characterize the diurnal evolution of the microphysics of the marine boundary layer stratus in order to advance our knowledge on this topic and to improve numerical prediction of the diurnal evolution in stratus microphysical structure.

OBJECTIVES

Objectives of the current work are:

1. Describe the diurnal variability of marine boundary-layer stratus (MBS) microstructure (including cloud depth, mean R_e, mean liquid water path (LWP), colloidal stability) and identify diagnostic variables for the presence of drizzle.
2. Test COAMPS performance in forecasting nocturnal MBS during DYCOMS-II (Dynamics and Chemistry of Marine Stratocumulus II) by comparing the results of model simulations to satellite and aircraft data analyses.
3. Develop a method to initialize marine boundary layer in numerical models with the satellite-retrieved inversion height and vertical temperature profile in order to improve the model predictions of the marine boundary layer cloud evolution.
4. Investigate the difference in cloud-top radiative cooling between daytime and nighttime. Investigate the influence of the cooling on boundary layer decoupling and cloud microphysics evolution.
5. Develop methods for retrieval of cloud physical parameters from nighttime satellite remote sensing data for use with the COAMPS mesoscale model to improve short-term forecasting of stratus evolution.

APPROACH

We are using the DYCOMS-II observational data set (both aircraft and satellite remote sensing), the COAMPS model, and the MM5 with improved initialization scheme to better predict the microphysics of the marine boundary layer cloud systems.

WORK COMPLETED

- Analyzed the DYCOMS-II aircraft data sets for all the research flights in detail.
- Investigated the cloud-top radiative cooling signature from the aircraft data and its importance in cloud microphysics evolution.
- Improved methods of nighttime satellite remote sensing data retrievals for cloud liquid water path and mean droplet diameter.
- Performed MM5 model simulation with the satellite-retrieved inversion height and vertical temperature profile in initialization.

RESULTS

Nighttime satellite retrievals: Aircraft and satellite data acquired during the DYCOMS II research program are providing new knowledge of the remote sensing signatures for aerosol effects in nighttime stratus layers. Figure 1 is an image obtained from GOES satellite data of the brightness temperature difference (BTD) between the thermal infrared and the near-infrared GOES Imager channels (11 um - 3.9 um BTD) with overlays of individual 15-minute flight tracks. This image is a composite of the tracks from four time periods. The period centered at 1015 UTC is shown in green, 1030 UTC in blue, 1045 UTC in cyan and 1100 UTC in red. GOES data has the advantage of 15-minute time resolution for matching to aircraft flight segments.

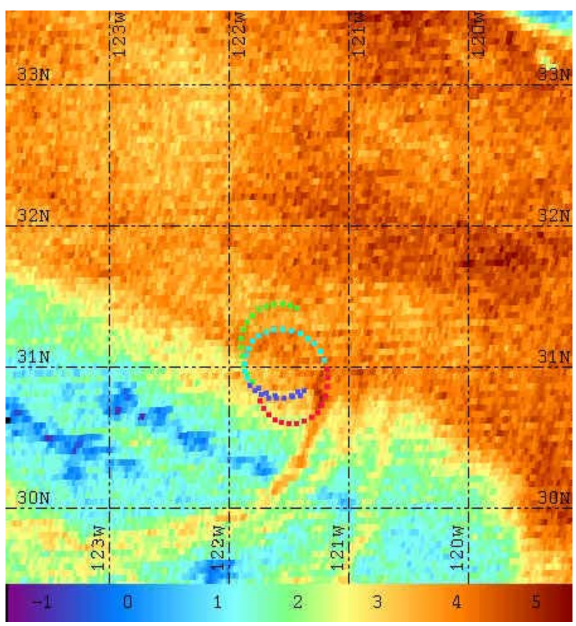

Fig. 1 GOES satellite data of the brightness temperature difference between the thermal infrared and the near-infrared GOES Imager channels (11 um - 3.9 um) with overlays of individual 15-minute flight tracks.

Aircraft sampling of the ship track line apparent in this figure was matched to associated with BTD values along the aircraft track, indicating reduced droplet size while the aircraft was circling at 520 m altitude as shown in Figure 2. Note the plot section at end of time series just before aircraft changed flight pattern. Near 11.10 UTC, the droplet mean diameter decreased from 12 to 9 um and liquid water content decreased to 0.3 g m-3 at flight level, during which time the BTD increased to 4.5 C.

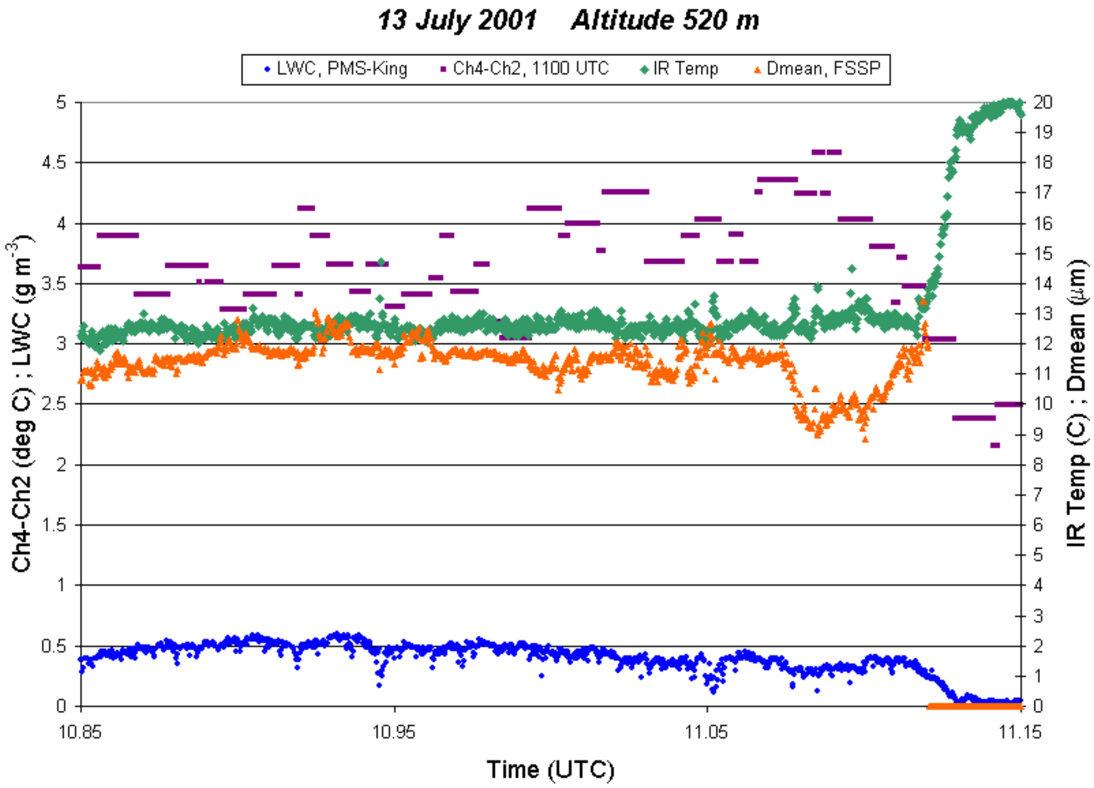

Fig 2. Aircraft measured liquid water content and droplet mean diameter, at 520 m altitude; along the ship track line (Fig. 1) was compared with associated BTD values.

Figure 3 puts these observations in context of a longer time series of aircraft data, for the 1000-1100 UTC composite period that covers the sequence of GOES images times. At time 11.10 UTC there is a reduction in droplet mean diameter and liquid water content coincident with the highest concentration in cloud droplets measured during this entire hour, and the time series indicates smaller droplet concentrations during the time period 10.4-10.7 UTC where the aircraft was in a zone of small BTD values (indicated by blue track segment in Figure 1). The smaller values of BTD associated with larger droplet sizes (mean diameter generally 12-15 um measured during this time period), and are related to the differences in cloud emissivity found by radiative transfer modeling of cloud with this range of droplet size. Thus, the nighttime bispectral method is indicating both small-scale (ship track) and mesoscale (air mass) patterns in droplet size that are important in identifying aerosol sources. Modeling of the bispectral radiative signatures for these clouds over multiple hours is being used to develop improved methods for using satellite remote sensing in short-term prediction of nocturnal cloud layer evolution.

DYCOMS-II data analysis: Uniform cloud fields topping a well-mixed layer were encountered in almost every flight mission during DYCOMS II. Analyses of the airborne data, with the help of a thermodynamic diagram show that the net radiative loss at cloud top effectively cools the cloud layer resulting in a cooler absolute potential temperature (θ_A, the temperature of the air, adiabatically lowered to 100 kPa with consideration of the liquid water in the parcel) of the cloud layer than the air below the cloud base. A hydrostatic instability between the cloud layer and the air below is thus created. With some triggering mechanisms, intermittent convection will take place in the marine boundary layer and a uniform absolute potential temperature throughout the boundary layer would then be reestablished. This radiative cooling effect is important not only in cloud dynamics but also in cloud microphysics. This can be seen more clearly on the θ_W vs. θ_A diagram (Telford and Chai, 1993). In this type of thermodynamic diagram, the θ_W vs. θ_A diagram, the dotted sloping lines are constant total mixing ratio lines and the solid sloping lines are the constant saturation pressure lines. These quantities, as well as θ_A and θ_W, are conserved during adiabatic motion of an air parcel with or without liquid water. Figure 4 shows the RF01/PF03 (Research Flight 3/Profile 3) data on the θ_W vs. θ_A diagram. All the points in the marine boundary layer are clustered in a small region ($\theta_W \approx 13.5^oC$, $\theta_A \approx 16^oC$) on this diagram, indicating that the layer is well mixed. Newly entrained parcels would be easily identified as they have lower r_v and θ_W values but higher θ_A values. However, the θ_W vs. θ_A diagram of RF01/PF04 shows that the data points in the cooled layer are aligned in a line parallel to a constant total mixing ratio line. This is an indication that the cooling is caused by long-wave radiative cooling from cloud top. The measurements of the air near sea surface are clustered in a region near 14^oC θ_W and 15.5^oC θ_A.

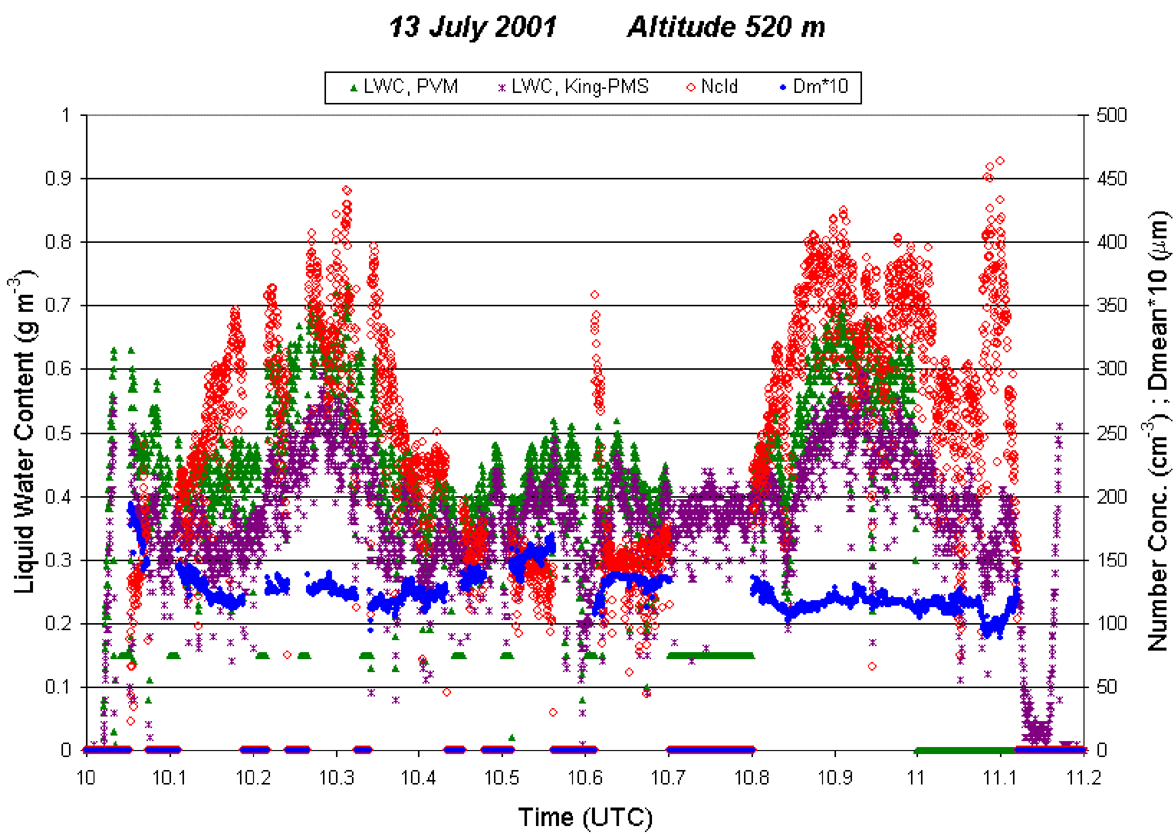

Fig. 3 Same as Fig. 2 but for the 1000-1100 UTC composite period that covers the sequence of GOES images times.

From analyzing the DYCOMS-II airborne data, it is shown that there were times where a layer of air, immediately under the inversion base, with cooler absolute potential temperature (Telford and Chai, 1993) and wet-bulb potential temperature, values than the air below while the total mixing ratio remains as a constant throughout the boundary layer. This radiative cooling signature was found periodically in all the research fights. This may be an indication of an intermittent nature of convection in the marine boundary layer. The effect of radiative cooling gradually diffuses downward by turbulent mixing, leading to a hydrostatically unstable layer. Any triggering mechanism may initiate the convective motion that leads to a well-mixed marine boundary layer.

The data suggests a link between these cooling signatures and the rates of cloud-top radiative cooling. After analyzing all the DYCOMS II data they suggest that the cooling signature appears mostly when the cloud-top heating rate is less than –15 K hr^{-1}. When the heating rate is more than –13 K hr^{-1}, no cooling signatures are found.

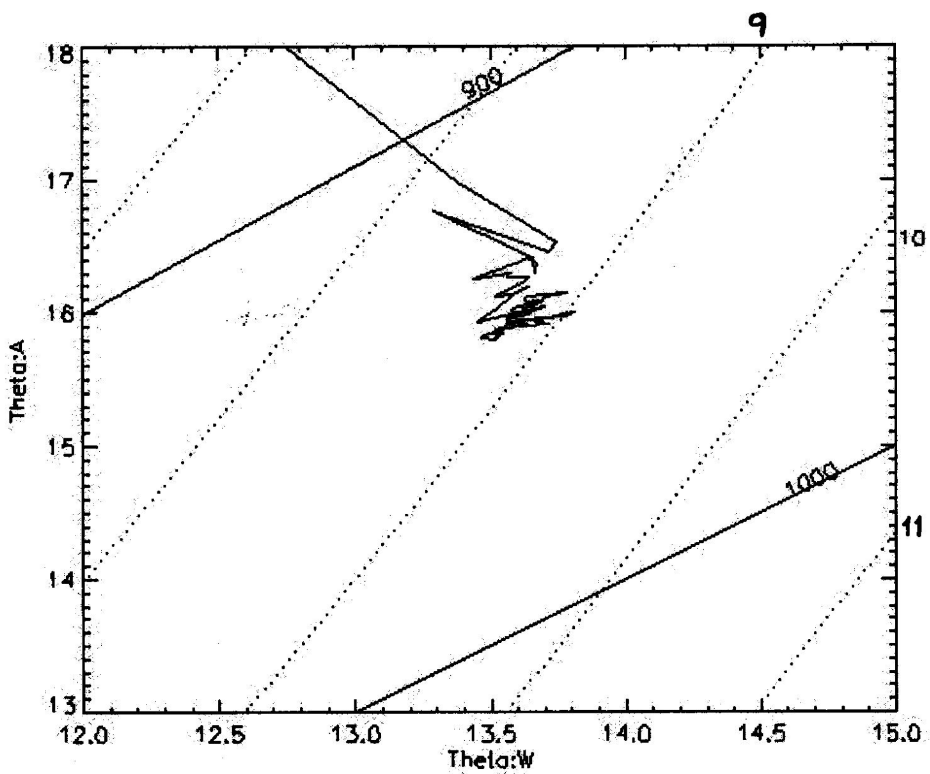

Fig. 4 The θ_A-θ_W diagram displays the RF01/PF03 data.

The intermittent nature of convection in the marine boundary layer and the radiative cooling effect are important in both cloud dynamics and microphysics. During periods with no convection through the whole boundary layer, the effect of entrainment on cloud droplet spectra broadening (Telford and Chai, 1980, Telford and Wagner, 1981, and Telford et al, 1984) may become effective and lead to faster drizzle formation. The effect of the entity-type entrainment mixing will be lost whenever the surface driven convection (either by water vapor flux or heat flux) mixes through the whole marine boundary layer. However, when the surface driven convection is not active, as indicated by the potentially unstable layer created by cloud-top radiative cooling, the entrained entities have time to circulate inside the cloud layer with continuous mixing with surrounding cloudy air that will lead to the broadening of droplet spectra. All of these mechanisms should be considered in numerical models in order to accurately predict the evolution of marine boundary-layer cloud systems.

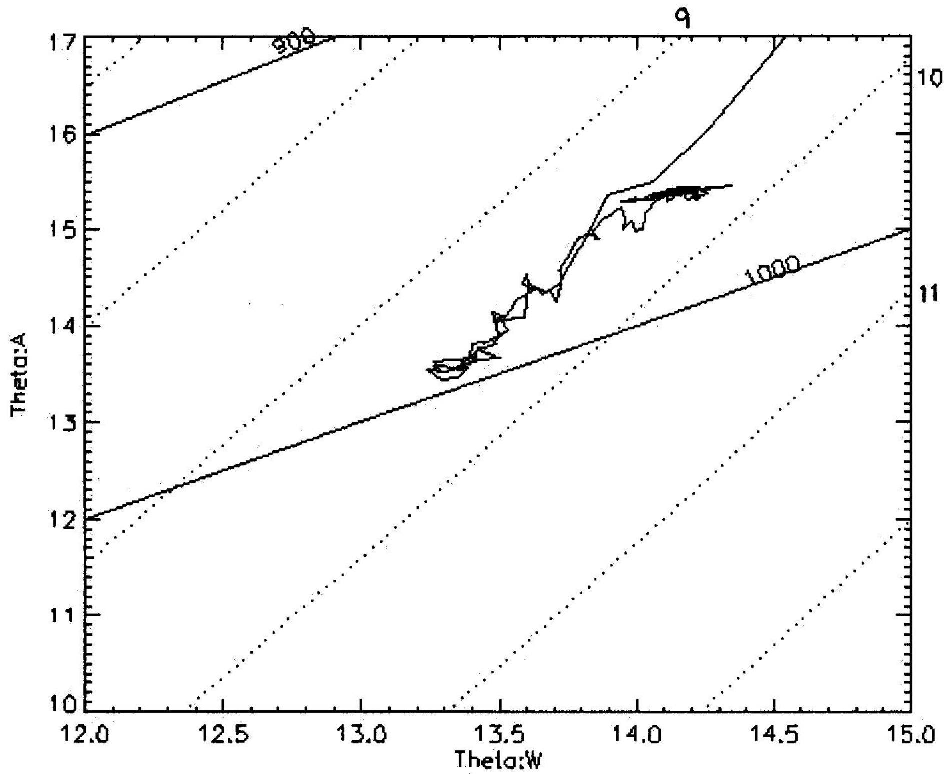

Fig. 5 Same as Fig. 4 but for RF01/PF04.

IMPACT/APPLICATIONS

The satellite remote sensing techniques will contribute to validation of the COAMPS model simulations for the DYCOMS-II study period.
The modeling task will improve our knowledge of the performance of various cloud microphysics schemes and indicate how to improve their performance in predicting the MBS systems.

TRANSITIONS

The DYCOMS-II data are posted on the web for use in scientific purposes by the COAMPS-II group. The data will be available to the entire scientific community soon.

RELATED PROJECTS

This research involves partnership with several other groups through the DYCOMS-II program (http://www.atmos.ucla.edu/~bstevens/dycoms/dycoms.html; http://www.joss.ucar.edu/dycoms).

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